



Implementing HPC on the Sunshine Bridge Project

Final Report 538

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16. Abstract This report presents the research work from a pilot program regarding the feasibility of implementing high performance concrete on Arizona bridge decks, using the Sunshine Bridge in Holbrook, Arizona as a test case. An existing concrete slab was removed and a new concrete slab using silica fume high performance concrete with low corrosion steel was constructed. Steps in the pilot program included developing a HPC mix design using laboratory tests of various batches. Field trial batches were conducted at a ready mix plant near the Sunshine Bridge to simulate job conditions such as concrete batching, travel time, plastic and hardened concrete properties. Test results indicated that a concrete mix design with 0.41 w/cm ratio and 5 percent silica fume by weight of cement provided overall optimum performance against project requirements. On-site slab demonstration placements of HPC at the bridge by the selected contractor simulated actual job conditions such as concrete batching, travel time, placement, finishing, curing, etc. The purpose of this field placement is to evaluate the contractor's procedures and crew. The bridge deck consisted of a total of 206 yards were placed at a rate of approximately 37 yards of concrete per hour on August 24, 2005. A comprehensive testing program measured and documented HPC properties and field practices as a reference for future bridge deck projects using HPC.					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
<u>LENGTH</u>					<u>LENGTH</u>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<u>AREA</u>					<u>AREA</u>				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	Square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	Square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	Square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	Square kilometers	0.386	square miles	mi ²
<u>VOLUME</u>					<u>VOLUME</u>				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	Cubic meters	35.315	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	Cubic meters	1.308	cubic yards	yd ³
NOTE: Volumes greater than 1000L shall be shown in m ³ .									
<u>MASS</u>					<u>MASS</u>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
<u>TEMPERATURE (exact)</u>					<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
<u>ILLUMINATION</u>					<u>ILLUMINATION</u>				
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
<u>FORCE AND PRESSURE OR STRESS</u>					<u>FORCE AND PRESSURE OR STRESS</u>				
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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I. EXECUTIVE SUMMARY

The I-40 Sunshine Bridge deck replacement was a pilot project conducted by the Arizona Department of Transportation (ADOT) to evaluate the feasibility of using High Performance Concrete (HPC) technology for bridges in the State of Arizona. The project consisted of replacing a cast-in-place concrete deck with a durable HPC deck reinforced with low corrosion steel.

A special provisional specification was written for the pilot project that emphasized HPC bridge deck construction technology and practices. The design performance criteria for the bridge deck were:

- Durability under freeze-thaw exposure
- Lower permeability to salt penetration
- Lower shrinkage potential
- Reduced steel corrosion

Silica fume, fly ash, and chemical admixtures were used in the HPC mix placed in the bridge deck and barriers. The reinforcing steel was a low-carbon steel with a corrosion threshold estimated to be five times higher than regular reinforcing steel.

Quality control and quality assurance programs were followed during construction to collect and document information about HPC's material characteristics and the construction practices that should be followed. Test results and field conditions confirmed the intended HPC properties were achieved on the majority of the bridge deck.

Challenges

The main challenges for the project were:

1. Ensuring aggregate properties and conditions at the batch plant were suitable for producing HPC
2. Controlling air content loss of pumped concrete on the deck
3. A short project schedule that prevented refinement of the HPC mix and field practices
4. Properly simulating the deck placement conditions due to the small size of the demonstration slab

These challenges are typical for a pilot project and are considered to be project-specific quality control. With the application of lessons learned on this pilot, we expect that future HPC projects can successfully address these issues.

Conclusions

The use of HPC in bridges by other state DOTs with similar climate and service conditions has reduced maintenance and increased the service life of structures. ^(1, 3 &5)

Our conclusions and recommendations include:

- An inspection and evaluation program of the Sunshine Bridge deck should be performed to monitor its performance.
- HPC can be implemented successfully on future bridge projects based on the test results and experience gained from the Sunshine Bridge project to date.
- The upfront investment in dollars and resources can be justified when ADOT considers the reduced maintenance and extended service life of bridge decks using HPC technology.
- Using HPC technology raises the bar in Arizona design and construction practices toward building bridges with better performance, longer service life, and safer driving conditions for the public.

The successful implementation of HPC on the Sunshine Bridge, despite the challenges encountered, is a clear indication that HPC can be used on bridges throughout Arizona where there are wide temperature ranges including freezing conditions (-18° to 109°F).



Figure 1. Aerial view of the completed Sunshine Bridge

II. INTRODUCTION

The Arizona Department of Transportation (ADOT) has recently implemented research on High Performance Concrete (HPC) technology conducted under State Planning and Research (SPR) Project 538. ADOT chose the I-40 Sunshine Bridge deck replacement over the Burlington Northern Santa Fe Rail Road (BNSF) railroad track as a pilot project (Project H618301C: Sunshine Bridge) to test the suitability of HPC for use in Arizona.

A. Purpose

The purpose of this project is to demonstrate the feasibility of using HPC for bridge decks. The work is also intended to gather information about HPC and the challenges and obstacles that ADOT expects to encounter as it implements HPC on future bridge projects throughout the state.

B. Scope of Work

The work presented in this report was authorized by ADOT's Transportation Research Center and was prepared in cooperation with the following groups:

1. ADOT Bridge Design Group
2. ADOT Holbrook District
3. Federal Highway Administration (FHWA)

The project was done in two phases: design and construction. The work done in each phase is outlined below.

1. Design Phase

- a) Visited the Sunshine Bridge area and reviewed the capabilities of local concrete suppliers to produce HPC. This included the concrete manufacturing facilities their procedures, and quality control programs.
- b) Performed laboratory tests on trial batches of concrete imported from the Sunshine Bridge area and selected one that best meets project criteria.
- c) Performed laboratory testing and evaluation of the selected concrete mixture made in the trial batches.
- d) Performed field trials on batches made at a ready mix plant near the Sunshine Bridge to simulate job conditions such as concrete batching, travel time, plastic and hardened properties.
- e) Wrote HPC specifications for the Sunshine Bridge Project using local materials. These specifications were included in the project bid documents.

2. Construction Phase

- a) Attended pre-construction meetings to address HPC implementation issues and project requirements.
- b) Pre-qualified the contractor for HPC implementation issues such as concrete materials, concrete supplier, mix design, concrete finishers, and other related construction and quality assurance/quality control, (QA/QC) programs critical to HPC.
- c) Monitored placement of an on-site HPC demonstration slab near the bridge by the selected contractor to simulate actual job conditions such as concrete batching, travel time, placement, finishing, curing, etc. The purpose of this field placement was to evaluate the contractor's procedures and crew capabilities and also to use it as a training exercise and an opportunity to make any project-specific adjustments to the specified installation procedures.
- d) Monitored field inspection and testing program to verify HPC plastic properties against project specifications.

The data collected from the Sunshine Bridge pilot will be used to evaluate the feasibility of using HPC in areas of cold weather climate in Arizona.

C. Background

The Sunshine Bridge (ADOT Bridge # 1390, Sunshine BNSF RR-OP WB,) is located between Holbrook and Flagstaff on westbound I-40 at mile post 237. The site is 5102 feet above sea level.

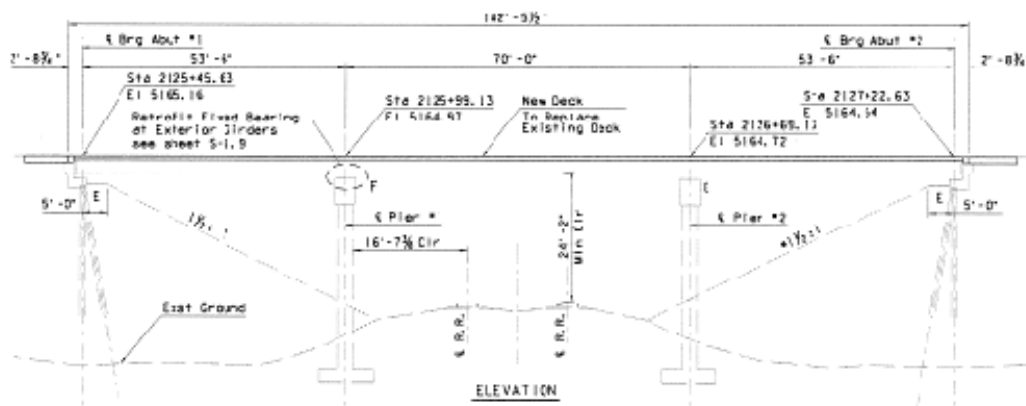


Figure 2. Bridge Elevation Profile

The bridge was built in 1968 by ADOT under project number I-IG-40-4(52). It consists of a 7.5 inch concrete deck supported by a three-span, five steel girder system with a skew of 42° 55'. The total Bridge length is 182.5 feet. (Reference

Figure 2, Figure 3, Figure 4, and Premier Engineering Corporation bridge construction plans).⁽⁸⁾ The project involved replacing the deteriorated concrete bridge deck that is supported by steel girders.

ADOT selected the Sunshine Bridge as a pilot project to evaluate the use of HPC on bridge decks in Arizona. The new bridge deck consists of a full thickness, cast-in-place concrete deck using state-of-the-art HPC technology.

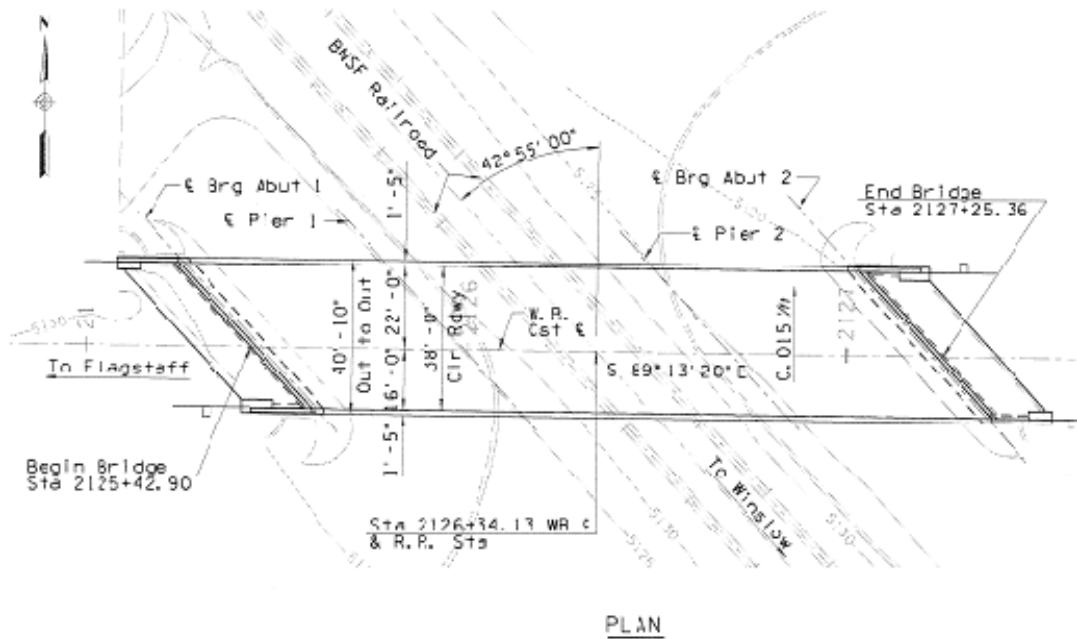


Figure 3. Bridge Plan

The Sunshine Bridge site presented the project team with several challenges:

1. *Short construction season.*-- The bridge is located in the Holbrook Construction District where the typical construction season starts at the beginning of May and ends in the middle of October. Construction on this project could not start until May 2005.
2. *All construction activities over the railroad tracks had to be completed by September 30, 2005* -- The railroad's traffic increases significantly in the last three months of the year. BNSFRR does not allow any construction activities within the railroad right-of-way during those months.
3. *Equipment access to the bridge deck from the railroad level was not feasible.* -- Because of railroad traffic and the 24-foot track clear zone, the contractor could not use a crane and bucket system or similar approach to deliver concrete onto the deck.

4. *The contractor needed a minimum of 90-days.* -- As the first ever implementation of HPC in Arizona, the contractor required at least 90 days to develop the HPC mix and make the necessary adjustments to meet project specifications. This left little room for variance in the construction schedule.

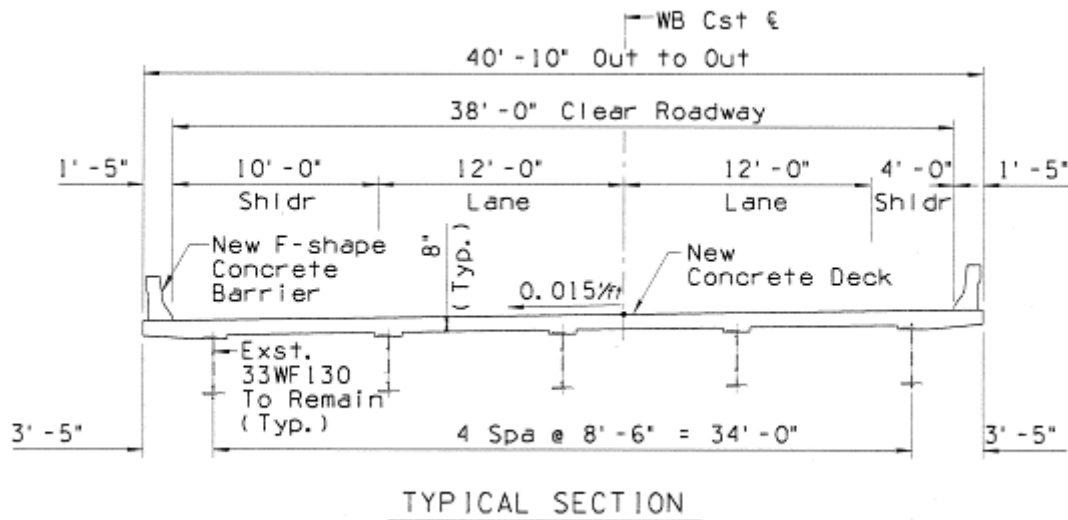


Figure 4. Proposed Bridge Section

III. HPC IMPLEMENTATION PROGRAM

The design team and ADOT selected the following concrete mix for the bridge deck:

1. An 8" full depth cast-in-place concrete deck.
2. A HPC mix according to the trial batches developed in the field.
3. A low carbon, low corrosion steel reinforcement (MMFX Steel).

The combination of durable concrete and low corrosion steel enhances concrete performance and extends the life of the bridge deck. HPC's low permeability reduces the penetration of chloride ions through the bridge deck. The low carbon steel has a corrosion threshold estimated to be five times higher than standard steel. This means the amount of chloride needed to initiate corrosion in the reinforcing steel is not only increased, but the amount of chloride reaching the steel has decreased.

A. Laboratory Trial Batches

Developing an HPC mix design starts with performing laboratory trials and testing. A typical testing program consists of making batches of proposed mixes using local materials and following project requirements. The batch testing for this project was conducted at Rinker Materials (Rinker) ready mix laboratory in Phoenix, Arizona. See Figure 5.



Figure 5. Laboratory Trial Batches

Concrete materials including cement, fly ash, and aggregates, were imported from the Sunshine Bridge area to Phoenix for the trial batches. Aggregates were tested in the laboratory to verify gradation and other performance criteria according to American Society for Testing and Materials (ASTM) and ADOT standards.

To achieve the optimum HPC mix design, Jaber Engineering Consulting, Inc. (JEC) made a total of six batches. Three batches had silica fume contents of 5 % and three had silica fume contents of 7% by weight of cement. Each of these sets with the same silica fume content was batched with a water-to-cementitious material ratio (*w/cm*) of 0.37, 0.41, and 0.45. The *w/cm* ratios were selected based on the best information currently available.^(3, 6)

Concrete from the trial batches was tested in both plastic and hardened states. In the plastic state, slump, temperature, air content, and setting times were measured. In the hardened state, samples were made to test the following properties:

1. Rapid chloride ion penetration (permeability)
2. Length change (shrinkage potential)
3. Resistance to freeze-thaw exposure (freeze/thaw)
4. Concrete compressive strength (strength)

Test results indicated that a concrete mix design with 0.41 *w/cm* ratio and 5 % silica fume by weight of cement provided overall optimum performance against project requirements (see Figure A-1, Appendix A):

1. Lowest possible chloride ion penetration: less than 1,200 coulombs.
2. Lowest shrinkage potential: less than 0.004 % for length change.
3. Best freeze-thaw resistance: a minimum of 85 % relative dynamic modulus.
4. Strength requirements: a minimum of 4500 psi at 28 days.

Using the laboratory test results in Appendix A, JEC developed a new concrete mix whose criteria were designed to optimize performance. Those criteria included: the lowest rapid chloride permeability, the highest freeze/thaw protection, and the required compressive strength range. The mix was field tested at a concrete ready mix plant close to the project site. The selected mix design and proportions are presented in Figure 6.

Concrete Materials	Weights
Portland cement, (lbs)	450
Fly ash, (lbs)	110
Silica fume, (lbs)	23
Fine aggregates, (lbs)	1181
Coarse aggregates, (lbs)	1765
Water, (lbs)	250
Water Reducer, (oz)	40
Superplasticizers, (oz)	18
Retarder, (oz)	20
Air Entraining Agent, (oz)	6
w/cm ratio	0.43
Paste content, (%)	27%
Air content, (%)	6.5%

Figure 6. Selected Mix Design

B. Developing the HPC Mix in the Field

Once the optimum mix design for the concrete was achieved at the laboratory, it was necessary to duplicate these results at the ready mix plant. At the plant the concrete was tested for both its hardened and plastic properties to ensure that the laboratory results could be repeated on a large scale field production. The ability to project results from the laboratory trials to a broad field application requires that the field trial batches be run using concrete material economically available to the contractors.

1. Selecting a Local Contractor

The design team was faced with a challenge of finding a ready mix supplier and a plant within a reasonable distance of the project. The project is located 40 miles from Flagstaff and 25 miles from Joseph City, Arizona, along I-40.

In cooperation with two ready mix suppliers, Rinker and Hanson Aggregates, the design team selected Quality Ready Mix (QRM), a subsidiary of Rinker in Joseph City, Arizona, to produce the field trial batches. The QRM plant, approximately 25 miles east of the Sunshine Bridge, was the closest ready mix plant to the project.

2. Batch Design

To demonstrate the improvement in concrete properties of HPC over a standard bridge deck mix, the design team elected to batch an ADOT Class S concrete mix, normally used by ADOT in bridge deck applications, for comparison.

On October 6, 2004, QRM batched a three cubic-yard load of ADOT Class S 4,500 psi concrete mix and a three cubic-yard load of HPC mix using the mix proportions developed in the laboratory trials (See Figure 7). The aggregate used in these trials was a river-rock type round aggregate from the Cottonwood Pit.

The concrete was centrally batched and discharged into trucks. To simulate and monitor concrete properties during travel time, the truck drum mixed at travel speed and was held at the plant for the anticipated travel time of one hour.

The concrete was tested at three stages: 1) right after batching; 2) during simulated truck travel time and; 3) at the end of the one hour hold period. The concrete's plastic properties, slump, air, and temperature were measured at the three stages and the results are shown in Figure B-1, Appendix B.



Figure 7. Testing HPC Trial Batches at the Ready Mix

3. Initial Sample Test Results

Concrete samples were cast at the batch plant and tested in the laboratory to measure the hardened concrete properties of the HPC mix against those of the ADOT Class S control mix.

The chloride permeability for the HPC was an average of 768 coulombs compared to 2610 coulombs for the control mix. The 70% reduction in coulombs is due to

the reduced permeability of the HPC over the ADOT Class S control mix. This reflects HPC's increased ability to resist chloride ion migration.

The HPC had an air void system with paste content of 23.5 percent, compared to 31.6 for the control mix. Since most of the concrete shrinkage comes from the cement paste, (cement and water), lowering paste content reduces the shrinkage potential of concrete.⁽²⁾ Air void systems for both mixes were sound and were expected to provide the concrete with durability under freeze-thaw conditions. Details of the laboratory test results are presented in Figures B-2 through B-9 in Appendix B.

C. Developing HPC Specifications

ADOT has used silica fume/HPC as a repair overlay on other bridge decks; however, the Sunshine Bridge is the first bridge deck in Arizona that uses HPC for the full deck. ADOT's current *Standard Specifications for Road and Bridge Construction* does not have provisions for HPC so the design team developed a special provisional specification to include in the bidding and construction documents.

Generally, there are two main approaches to specifying HPC for bridge deck construction:

1. ***Performance Specification:*** Specify the concrete performance criteria required for the bridge deck and require the contractor to achieve those criteria.
2. ***Prescriptive Specification:*** Require the contractor to follow certain procedures and use specific materials and/or proportion methods to achieve the performance criteria intended for the project. The contractor is not responsible for ensuring concrete performance properties are achieved provided the specification requirements are followed.

The *performance specification* is used when the contractors expected to bid on the project have prior experience with HPC. The owner normally relies on contractor knowledge and experience to achieve the required performance criteria.

The *prescriptive specification* is used when the contracting community has limited knowledge and experience in working with HPC and may have difficulty achieving the desired results.

Based on the preliminary research work performed in the field and laboratory, the design team and ADOT selected the prescriptive specification approach for this project.

The following factors played a significant role in selecting the prescriptive specification approach.

1. *First full bridge deck.* – ADOT's previous use of HPC was limited to overlays; this is the first project to use HPC for the full deck and traffic barriers.
2. *Lack of experience by local contractors and suppliers.* – There was a limited number of contractors and concrete suppliers in the project area with adequate experience in producing and constructing with HPC.
3. *Potential cost advantage of prescriptive specification.* - Contractors would increase their project bid because of the perceived risk they would face in using an unfamiliar product.
4. *Project construction schedule.* – The short construction schedule allowed minimal time for the contractor to develop a concrete mix for the project that was based on performance.

D. Project Bidding

The project was advertised; bids were opened on March 25, 2005. Vastco Construction Inc. (Vastco), headquartered in Flagstaff, was the successful bidder. Rinker won the ready mix supply contract. ADOT's Holbrook District managed the project. ADOT gave Vastco a notice to proceed on April 15, 2005.

E. Pre-Construction Work

A day-long project partnering meeting with representatives from all firms and agencies involved in this project was held on May 19, 2005. The challenges of implementing HPC were discussed in detail, with input from Vastco, ADOT, and the design team. The design team also presented a schedule of milestones showing the time and sequence of significant events that would lead to a successful deck placement. (See Figure C-1, Appendix C.)

A quality control plan was also developed at the partnering meeting that detailed the steps in the concrete deck placement process from concrete production at the batch plant through final concrete curing. The plan, shown in Figure D-4, Appendix D, outlined each project member's role, duties and responsibilities during the deck placement, including the responsibility of accepting each truck load of concrete before placement.

1. Trial Batches

Rinker elected to supply the HPC from its Flagstaff plant. Vastco/Rinker made five trial batches between May 18 and June 29, 2005. **None of the trial batches achieved the desired field properties for slump, air and w/cm ratio.** (Details of the trial batches are presented in Figure C-2, Appendix C.)

a. Discussion and Comments

ADOT and the design team were at the Rinker ready mix plant during the trial batches. Concrete mix, materials, and proportions were reviewed to verify compliance with project specifications. Concerns centered on the aggregate properties in the failed batches.

The coarse aggregates used in the trial batches were 100% crushed basalt aggregates. The basalt appeared to be a mix of approximately 40% porous and absorptive rock and 60 % harder, angular rock.

The aggregates appeared to have varied moisture conditions and seemed to be below the Saturated Surface Dry (SSD) conditions specified for the project, when visually examined at the stock pile. The low SSD conditions were later confirmed in lab tests performed by Rinker.

Because of its low and varied moisture conditions, the aggregate absorbed large portions of the mixing water during the initial stages of batching. This caused water demand to increase and made it difficult for the concrete mixture to achieve the required slump. Air content was also variable and unstable when the slump and water demand fluctuated as a result of the aggregate moisture conditions.

It was clear that the variations in aggregate moisture and the below-SSD conditions of the aggregate caused many of the trial batches to fail. The angularity of the aggregate also increased water demand compared to the mix tested during the trial batches made at QRM on October 6, 2004. The mix design proportions specified in the project documents were based on trial batches using the Cottonwood Pit aggregates. The aggregate used by Rinker for the project was from the Cherry Pit.

Because of its angular shape, the Cherry Pit coarse aggregate has higher water demand compared to the river rock type round aggregate from the Cottonwood Pit. A summary of the aggregate moisture properties by source is shown in Figure 8. Detailed properties are presented in Figure A-6 in Appendix A and Figure C-5 in Appendix C.

Aggregates Absorption			
Aggregate Source	Application	Sand	Rock
Cottonwood Pit	Trial batches, laboratory and field	0.97	0.73
Cherry Pit	Project batches and bridge deck	2.20	1.60

Figure 8. Aggregate Moisture Properties Comparison

Vastco and Rinker requested that ADOT and the design team make the following changes:

- i. *Modify the project requirement for accepting the HPC compressive strength from 28 days to 56 days.* Rationale: The fly ash in the mix will continue to gain strength well beyond 28 days. Moving the compressive strength from 28 to 56 days will discourage the contractor from trying to increase cement content to achieve higher strength at 28 days.

Delaying concrete strength gain to later ages (by reducing cement content and adding fly ash) will generally make concrete less susceptible to cracking ⁽³⁾. ADOT and the design team approved this change.

- ii. *Increase the specified maximum concrete temperature at placement from 80° to 85° F.* The purpose for this request is to avoid using ice in the batching process. It is generally difficult to control w/cm ratio when ice is added to the mix.

In the interest of maintaining and controlling the w/cm ratio, the design team did not object to an increase in the maximum allowed concrete temperature on deck from 80° to 85° F. The potential 5° F increase in concrete placement temperature has far less impact on the quality of concrete when compared to the potential of higher w/cm ratio ^(2,6).

- iii. *Increase fly ash content from the specified 110 lbs to 165 lbs.* The purpose of the additional fly ash is to increase the paste content in the concrete mixture and overcome the low slump and air instability caused by the low and variable moisture conditions in the aggregate.

To accommodate this field condition, ADOT and the design team allowed Rinker to proceed with the fly ash increase provided all other concrete plastic properties were maintained.

b. Adjustments & Recommendations

To help achieve the required HPC mix design, ADOT and the design team approved the contractor-proposed changes and made the following recommendations:

- i. The aggregate needed to be at SSD conditions 24 hours before batching the HPC, as required by Project Specification's Section 1006-2.03(B) and (C). Project specifications were developed by the design team in tandem with ADOT's Contracts and Specifications Section.
- ii. The silica fume content should be adjusted from 25 to 30 pounds.
- iii. The HPC mix w/cm ratio should comply with the project requirement of minimum 0.40 and a maximum of 0.42.
- iv. The contractor should produce additional batches incorporating these recommended adjustments to ensure consistent concrete production.

ADOT and the design team approved those changes and recommendations to accommodate the limitations of Rinker's materials, mainly the aggregate's increased water demand and its moisture conditions at the plant.

Using the approved changes, Rinker made trial batches # 6 and # 7 on Wednesday July 6, 2005. Batch # 6 was not successful. Batch # 7 had a 0.402 w/cm ratio, an 85° temperature, and an air content of 4.6% at 50 minutes after the concrete was batched so the project team considered it tentatively successful, but saw that further refinement would be needed during the required field demonstration. (See Figure C-2 for details of the tests on the trial batches.)

3. Field Demonstration

Project specifications required the contractor to perform a field demonstration of the concrete deck placement. A successful demonstration would simulate field conditions anticipated during actual deck placement. The specification would allow the contractor the option to use the bridge approach slab or other slabs at locations close to the project for the demonstration. Vastco elected to use the approach slab.

a. Slab Demonstration # 1

The first field demonstration took place on August 5, 2005 using the east approach slab. The slab was approximately 46' wide by 15' long; too small for a Bidwell finishing machine to be used. Concrete was delivered to the

site in three truckloads. Placement using a 42' Schwing pump began at 2:27 a.m. and concluded by 3:05 a.m. The contractor used a portable vibratory screed to finish the concrete surface (See Figure 9). Details of placement locations and properties of the concrete are presented in Figures C-4a and C-4b in Appendix C.

The first demonstration was considered unsuccessful as the project crew was unable to satisfactorily place and finish the slab. The design team requested a second slab placement demonstration to ensure that the contractor could follow proper HPC techniques prior to actual deck placement.



Figure 9. Slab Demonstration No.1

b. Slab Demonstration # 2

The second field demonstration took place on August 18, 2005 using the west approach slab. The slab was similar in size to the east approach slab but was too small for finishing machines to be used.

The air loss encountered through the pump remained unresolved in the second slab demonstration. As with the first demonstration, the crew did not follow proper HPC techniques in either placing or finishing the slab. Therefore, the slab demonstration was considered unsuccessful. Reference Figure C-3 Appendix C for demonstration slab test results.

F. HPC Deck Placement

Despite the fact that both field slab demonstrations failed to meet project specifications and therefore did not fully meet with ADOT's and the design team's approval, the need to complete all construction activities on the bridge by the end of September 2005 remained. To meet the BNSFRR deadline, ADOT allowed Vastco to proceed with deck placement. The deck placement was scheduled for 2:00 a.m. August 24, 2005.

A pre-placement meeting of the design team, ADOT, Vastco and Rinker was held on August 22, 2005 in Flagstaff. The project team reviewed the deck placement procedure, the quality control and the quality assurance plans that were developed during the partnering workshop (See Figure D-4, Appendix D).

Because of site conditions and traffic access restrictions, the contractor used two concrete pumps. Pump No.1, a 52-meter Putzmeister, (M52), was set up on the east end of the deck. Pump No.2, a 45-meter Schwing (M45), was set up on the west end of the bridge deck.

Concrete placement started on the east end using pump No.1. At approximately the midpoint of the bridge deck, beginning with load no. 12, concrete placement was continued from the midpoint to the west end using pump No.2. The Deck Placement Schematic Layout is shown in Figure D-5, Appendix D.

1. At The Batch Plant

QA/QC tests were carried out by the project team at the batch plant and on site. Vastco and Rinker's QC program included:

- a. Measuring concrete materials' weights
- b. Measuring the moisture conditions of both the coarse and fine aggregate
- c. Testing concrete properties – slump, air content, and temperature- for compliance with specifications before the concrete trucks left for the site

Both ADOT and JEC performed a QA program to verify the information measured and tested in the contractors' QC program. The QA program included:

- a. Batch plant observation during concrete production to verify that concrete batches met the approved concrete mix design. The observation was performed by a Registered Professional Engineer who documented concrete batch weights, moisture conditions, and calculated the w/cm ratio. The purpose of the w/cm calculation was to inform ADOT to alert the contractor should the w/cm ratio exceed the maximum of 0.42 allowed in the specifications. Figure D-2, Appendix D includes concrete batch

weights and their variance from the proposed concrete mix design and a tabulation of the w/cm ratio for each load. A graphic representation of the w/cm ratio for each concrete load is presented in Figure D-3, Appendix D.

- b. Testing of concrete properties-slump, air content, and temperature- for compliance with specifications and to confirm testing performed by the contractor before concrete trucks were allowed to travel to the site.

The slab demonstrations showed that air loss between the batch plant and the deck was 3.38 % during the first demonstration and 4.06 % during the second demonstration, an average of 3.72 % air loss for both placements. See Figure C-3 Appendix C. Based on this information, and to achieve the specified 6.5 % air content at placement, the project team agreed that concrete would be allowed to proceed to the job site only when the following plastic properties were achieved in the concrete batched at the plant:

- a. Minimum air content of 10 %
- b. Minimum 9 inch slump
- c. Maximum temperature 80° F

The higher-than-specified air content was permitted at the batch plant to allow for the anticipated loss during transportation and pumping. The higher than specified slump was deemed necessary to maintain air in the concrete. Concrete drivers were not permitted to add water to the concrete mixer until the concrete was completely discharged.

The first concrete truck was batched at 1:02 a.m. and the last at 7:00 a.m. Twenty one trucks delivered 206 cubic yards of concrete.

2. Arrival of Concrete On-Site

Two testing stations were set up in the median approximately 100 feet ahead of the concrete pump on both sides of the bridge deck - Test Station 1A was at the median entrance ramp east of the bridge. Test Station 1B was at the median entrance ramp west of the bridge. For details on testing stations and locations see Figure D-5, Appendix D.

On arrival at the testing stations, the concrete was tested for slump, air content, and temperature by Rinker's QC technicians and ADOT inspectors before proceeding to the pump. Any adjustments to the concrete plastic properties were made using chemical admixtures such as air entraining agents or superplasticizers.

The concrete was allowed to proceed to the pump only when slump was at least six inches and air content was a minimum of 9%

3. Concrete Placement

Actual concrete placement on the deck started with the discharge of concrete truck load no.1 at 2:37 a.m. and ended when truck load no. 21 was completely discharged at 8:10 a.m. A total of 206 cubic yards were placed at a rate of approximately 37 cubic yards per hour.

Placement started on the east end where concrete was pumped on deck through pump No.1. The first two trucks were tested before placement and showed air contents of 9.5 % and 8.8 % respectively before pumping. Air content for the second truck's load was measured at 2.5 % after pumping showing an air loss of 6.6 % through the pump. Vastco and Rinker took quick measures to reduce air loss through the pump, including adjusting pump line configuration, reducing pump pressure, installing an S-pipe at the end of the pump hose, and even laying the pump hose flat on the deck. Note S-pipe use in Figure 10.



Figure 10. Pumping Concrete Using an “S” Pipe

The measured air content on the deck for the first eight truck loads (80 cubic yards of concrete) remained below the required 5.5 % minimum, despite all attempts to control air loss through the pump. Details of air content loss are presented in Figure D-1, Appendix D. ADOT Inspector Denise Hamill made a field sketch showing the approximate placement of every truck's load placed on the deck. The hand sketch is presented in Figure D-7, Appendix D.

When concrete had been placed on the eastern half of the bridge, the trucks switched to delivering the concrete to the west end where concrete pump No.2 had been set up. The concrete was checked at testing station 1-B at the west

entrance ramp and adjusted when needed for slump and air content. Trucks were allowed to proceed to the pump only when slump, air content, and temperature met project specifications.

4. Concrete Testing and Sampling

Concrete was tested and sampled by ADOT, Rinker, and JEC. Samples were taken from concrete placed on the deck at the end of the pump hose. The fresh concrete was transported off-deck to the west end of the bridge using wheelbarrows traveling on wooden planks set across the deck's reinforcing steel. Test samples were cast and cured on-site for the following purposes:

- a. Contractor confirmation of Compressive Strength. Rinker made one set of 6"x12" concrete cylinders for every 20 yards of concrete placed on-deck. The cylinders were tested in the laboratory for compressive strength. Testing and sampling of concrete was made by ACI-certified field technicians.
- b. ADOT Confirmation of Compressive Strength. ADOT made one set of 6"x12" concrete cylinders for every 20 yards of concrete placed on-deck. The cylinders were tested at ADOT's Materials Laboratory for compressive strength. ADOT compressive strength test results were used for concrete acceptance according to project specifications. The testing and sampling of concrete was performed by ADOT-certified field technicians.
- c. JEC Confirmation of HPC properties. JEC retained Western Technology, Inc. (WTI) of Phoenix, Arizona to take test samples. The purpose of this testing was to verify and document HPC properties. The laboratory tested chloride permeability, freeze-thaw resistance, scaling resistance, modulus of elasticity and shrinkage potential. Test samples were cured on-site for 24 hours and later transported to WTI's laboratory in Phoenix for curing.

A summary of the field testing and sampling of the concrete is presented in Figure D-1, Appendix D.

5. Concrete Finishing:

Vastco used a Bidwell finishing machine mounted across the bridge deck on a fixed railing with double rotating augers and a roller screed. After concrete was discharged on-deck and vibrated, the roller screed made one pass across the deck, followed by a paver pan to drag-close the surface. See Figure 11.



Figure 11. Concrete Finishing Machine

Minimal surface finishing was performed to avoid cracking the HPC. Surfaces between the machine rail and the furthest reach of the roller screed were hand-finished as shown in Figure 12.



Figure 12. Finishing Areas Next to the Machine Railing

6. Concrete Protection and Curing

Project specifications required the contractor to “begin curing the concrete surface no later than 10 minutes after it is finished” and that “the finishing machine cannot be more than 10 feet away from the finished surface.” To accomplish this, Vastco set up a working bridge traveling behind the finishing machine and used it to place the curing sheets as shown in Figure 13.



Figure 13. Working Bridge to Lay Down Curing Sheets

The burlene sheets used for curing are made of burlap on one side and plastic on the other, with holes in the sheets to allow added water for curing pass-through. The contractor placed the burlene across the entire width of the bridge deck. Soon after the burlene sheets were laid on the concrete surface they were wetted down to keep them in place as shown in Figure 14. Wet curing of both the concrete deck and the barriers continued for 14 days which provided the water needed for cement hydration.



Figure 14. Wetting Down Curing Sheets

7. Laboratory Test Results

Because the project was designed with a prescriptive specification approach, the contractor was not required to meet any HPC performance requirements except for compressive strength. Therefore, a special concrete testing program was authorized by ADOT and carried out by JEC. The purpose of the laboratory testing program was to measure the performance properties of the HPC placed on the Sunshine Bridge deck and confirm compliance with project requirements.

Samples were tested at WTI in Phoenix and at Construction Testing Laboratories (CTL) in Skokie, Illinois. A summary of all laboratory test results and reports is included in Figure E-1a, Appendix E. Results of compressive strength tests from ADOT, Rinker and WTI are summarized in Figure E-1b, Appendix E.

Figures B-2, E-1a and E-1b compare the properties of the HPC placed on the bridge deck to an ADOT class S mix. The rapid chloride permeability (RCP) of the bridge deck concrete was reduced three fold by using HPC instead of class S concrete. RCP results were 768 and 984 coulombs for HPC compared with 2610 for class S concrete.

IV. CHALLENGES AND LESSONS LEARNED

The Sunshine Bridge pilot project was an excellent test case for using HPC technology on Arizona bridges in freeze-thaw environments. The obstacles and challenges the project team faced presented everyone the opportunity to gain knowledge and experience in bridge deck construction.

The following lessons were part of the learning process that came out of the Sunshine Bridge pilot project.

1. Aggregates Quality and Conditions

Aggregate properties such as shape, absorption, water demand, and moisture conditions at batching time are major factors that need to be addressed when HPC is specified on a project. The coarse and fine aggregates proved to have the most significant impact on getting the HPC mix to meet field performance requirements.

A specific QC program for aggregates needs to be established by the supplier and approved by ADOT and the design team. The QC program should be a pre-requisite of any successful HPC project.

2. Batching Based on w/cm Ratio:

Ready mix suppliers in Arizona need to make the transition from their current practice of concrete batching based on slump to batching based on w/cm ratio. HPC in bridge applications focuses on durability that is associated with the w/cm ratio. To meet requirements, coarse and fine aggregate should be at SSD weights at batching time, and moisture of the aggregate should be regularly measured during batching to calculate and confirm the w/cm ratio.

3. Concrete Transportation

Concrete slump and air content at the batch plant may need to be higher than what is required at placement to compensate for losses during transportation and pumping. Concrete properties change during transport and since many bridges are long distances away from ready mix plants, maintaining the concrete's properties during travel is a critical issue that requires special planning and design considerations. Performing trial batches at the batch plant is the best way to address this issue.

For the Sunshine Bridge a minimum of 9 inch slump and a minimum of 10 % air content were required at the batch plant to allow for air losses during travel and passage through the pump.

4. Field Demonstration

Performing field demonstrations of concrete placement is an essential step in a successful HPC project. The demonstration allows the project team members to practice all steps of the concrete placement and identify and solve problems ahead of the actual deck placement. The placement slab area should be large enough to allow for placement, finishing machine, and finishing techniques to be demonstrated. Time should be allowed for conducting multiple field trials and demonstrations should they be needed.

All team members should be present to provide their input on the process and reinforce their role during deck placement. It is critical that the crew performing the field demonstration be the same as the one that will perform the actual deck placement. The demonstration should cover all aspects of deck placement including travel time, pumping, finishing, curing, and other site-specific requirements.

Future HPC projects should allocate a separate pay item for a slab demonstration. The pay item can be allocated in two ways:

- Pay directly for the cost of all materials, labor, and equipment for the demonstration.
- Pay according to size of the demonstration slab. Payment should be for successful placement only.

5. Concrete Pumping

The amount of concrete air content loss through pumping must be determined through trial batches and field demonstrations before deck placement. Concrete properties must be measured **on-deck** to see if they meet acceptance criteria, because the properties of the concrete ultimately placed and finished on-deck are the ones that determine a bridge deck's performance.

Air content in concrete should be increased before pumping in the amount pre-determined during earlier trial batches and field demonstrations to allow for air losses through the pump, so the concrete placed on-deck meets project requirements.

To compensate for air losses during transportation and through the pump, the concrete for the Sunshine Bridge was batched at higher levels of air content than the project-specified on-deck air content of $6.5\% \pm 1.5\%$. Concrete was batched at 9-10% to allow for an anticipated air loss of 3.72% measured during the field demonstrations. Air content impacts concrete performance in the following ways:

- Increased air content improves concrete workability.
- Entraining a good air-voids system in concrete helps protect it against freeze/thaw damage and increases its durability under severe exposure conditions.
- Concrete strength is reduced when air content in concrete is increased.

When placing the concrete by pumping, the contractor should use the same pump used for establishing the air loss during trial batches and slab demonstration.

6. Wet Curing

Future HPC bridge project specifications should be written to alert the contractor to the importance of wet curing and its impact on the construction schedule.

Membrane curing is the common practice for bridge decks in Arizona. HPC requires wet curing for at least 7-14 days.

7. Constructability

There were no real constructability issues in using HPC on the Sunshine Bridge. Although there were difficulties in developing the concrete mix at the batch plant and controlling air content loss through the concrete pump, most of the problems encountered were related to quality control issues that can be readily addressed on future projects.

The impacts of wet curing on the schedule must be addressed early. Wet curing for 7-14 days is required for optimal performance of HPC.

Testing needs will decrease as knowledge is gained. The concrete sampling and testing program was extensive and unique to this project because of ADOT's objective to establish a base reference for HPC performance. The extent of HPC testing programs on future HPC projects may be reduced as more information about HPC technology becomes available.

8. Safety

An HPC bridge deck requires less frequent maintenance than a conventional concrete bridge deck. Reduced maintenance results in fewer accidents, injuries, and fatalities. FHWA statistics on the relationship between maintenance/construction and the number of accidents and deaths show that the U.S. has:

- One work zone fatality every 7 hours (3 a day)
- One work zone injury every 15 minutes (96 a day)
- A financial loss of \$3 billion from work zone crashes in 2001

For more information go to the following link:

http://safety.fhwa.dot.gov/wz/nwzaw_events/factsheet04.htm

9. Team Members Feedback

Feedback from project team members should be considered for future HPC projects. In order to get the input from project team on the implementation of HPC on the Sunshine Bridge project, a meeting of all participants was held on February 7, 2006. Comments from the meeting are presented in Figure D-7, Appendix D.

V. CONCLUSION:

The test results and field experience suggest that using HPC on bridge decks in Arizona is feasible and can result in improved concrete properties. In the early stages of using HPC on bridge decks cost increases can be expected as bridge contractors develop experience and knowledge in HPC technology. These costs will decrease as a result of more competitive pricing when more HPC projects are constructed and more contractors become familiar with HPC.

The design team recommends that an inspection and evaluation program of the Sunshine Bridge deck be performed to monitor HPC and bridge performance establishing the benefit of an HPC deck compared to other bridge decks in Arizona.

Based on the testing, field experience, and lessons learned on this project, the design team recommends that more bridge decks in Arizona be constructed using HPC. However, further field observations are recommended to confirm field performance and establish a base line for concrete performance. We recommend that a five-year field monitoring program be initiated to accomplish this goal.

The upfront investment in dollars and resources is justified when the reduced maintenance and extended service life of bridge decks using HPC technology are considered.

VI. REFERENCES

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